Performance of XeF/KrF Lasers Pumped by Fast Discharge

Prepared by C. P. WANG
Aerophysics Laboratory

26 February 1976

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ABSTRACT

The output energy and pulse shape of XeF/KrF lasers pumped by fast discharges were measured at various gas compositions and total pressures. For the KrF laser, the maximum output (1.6 mJ) was obtained in a gas mixture of He:Kr:NF_3 = 100:5:0.2 at a total pressure of 700 Torr. The output energy density was 160 mJ/l, and the wall-plug efficiency was 0.06%. The peak power was 55 kW. For the XeF laser, the maximum output (10 mJ) was obtained in a gas mixture of He:Xe:NF_3 = 100:4:2 at a total pressure of 500 Torr. The peak output power was 1 MW. The output energy density (660 mJ/l) was a factor of 10 higher, and the wall-plug efficiency (0.5%) was a factor of 2.5 higher than reported earlier.

ACKNOWLEDGMENT

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I. INTRODUCTION

The rare gas monohalide lasers are a new class of efficient, high-power lasers operating in the ultraviolet. The laser action has been predicted and subsequently demonstrated by direct electron-beam excitation,[1-5] electron-beam-controlled discharge excitation,[6] and fast-discharge excitation.[7-9] Lasers in XeF with wavelengths of 351, 353, and 349 nm and in KrF with wavelengths of 249 and 250 nm have produced the greatest powers and efficiencies. The performance of these lasers, however, is still far from optimum because the excitation mechanism, gas kinetics, fast discharge, and plasma stability are not well understood. The operating conditions, such as total gas pressure, species concentration, and discharge (or electron-beam) voltage and current have not yet been optimized.

Since the demonstration of laser action by a fast-discharge device[10] in XeF[8] and in KrF,[9] an order of magnitude improvement in laser performance has been achieved by systematically varying the gas pressure, gas composition, discharge voltage and current, and line impedance. Preliminary results are reported here on the output energy and pulse shape of fast-discharge-initiated XeF/KrF lasers as functions of total gas pressure and gas composition. The significance of this study is that optimum gas compositions and pressures as well as the general behavior of the laser performance are obtained for several voltage levels. Also, data are provided for the theoretical modeling of XeF/KrF laser performance.

II. EXPERIMENTAL RESULTS

The construction and discharge characteristics of the fast-discharge device have been described earlier.[10] Briefly, it is a Blumlein-type fast-discharge device with a discharge duration of 10 nsec. The width of the line (50 cm), the length of the line (100 cm), and the height of the electrode (0.33 cm) are all fixed. The electrode separation, however, can be varied from 0.5 to 2 cm; the line impedance can be varied from 0.04 to 0.20 ohms; the discharge voltage can be varied from 5 to 20 kV; and the gas pressure can be varied from 20 to 700 Torr. The most important features of this fast-discharge device are: fast rise time, variable line impedance and electrode separation, and the capability to operate at high pressures without excessive arcing.

The laser output energy was measured with a Molectron joulemeter (Model J3-05) with fine-mesh screen attenuators. The laser output pulse shape was monitored with an ITL fast vacuum-photodiode (100 psec rise time) and a Tektronix 7844 oscilloscope with a 7A12 plug-in unit. The output wavelengths were measured with a Jarrell-Ash 1/2 m grating spectrograph.

For the KrF laser, a discharge volume of $0.6 \times 0.33 \times 50\ cm = 10\ cm^3$ and line impedance of 0.05 ohm were used. The discharge voltage was 8 kV. The laser cavity was a 4 m radius-of-curvature dielectrically coated total reflector with 98.5% reflectivity and a flat dielectrically coated output mirror with 95% reflectivity. The separation between mirrors was 90 cm. These mirrors were mounted internally, without Brewster windows, in order to reduce losses. The measured output wavelengths were 248.5 and 249.5 nm.

Gas mixtures of He, 5-20% Kr, and 0.2-0.4% NF_3 were used at total pressures of 200-700 Torr. The measured output energy versus total pressure for various concentration of Kr and NF_3 is plotted in Fig. 1. Each measurement was obtained by averaging over more than ten pulses at a pulse repetition rate of 1 Hz. With a single filling of gas mixture, several hundred laser pulses can be obtained with little or no degradation of output energy.

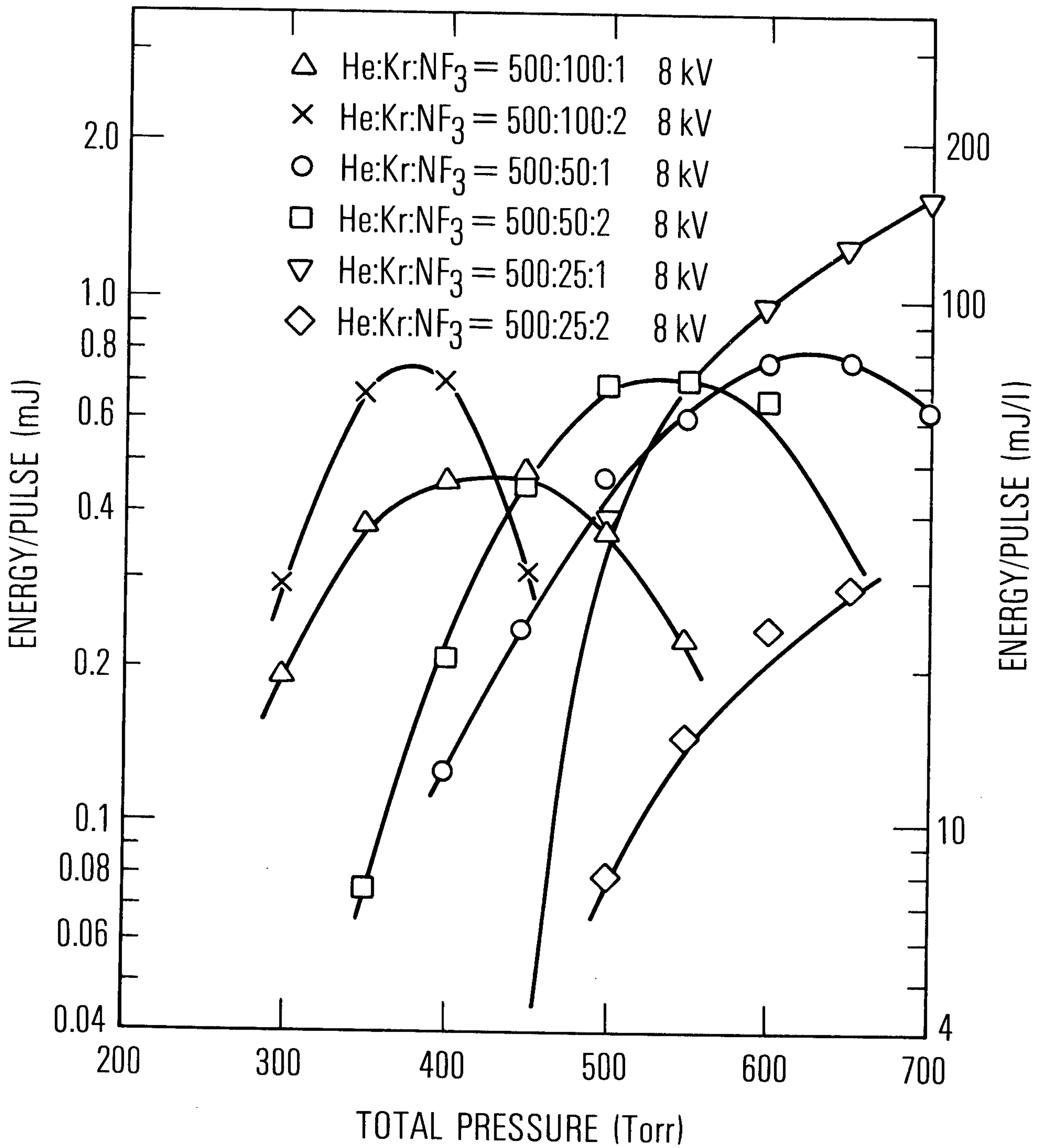


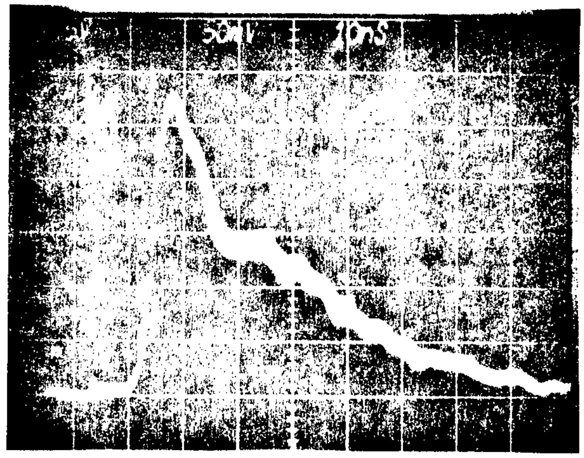
Figure 1. Measured Output Energy vs Total Pressure for Various Kr and NF_3 Concentrations

The experimental result (Fig. 1) shows that, for high Kr concentrations (He/Kr = 5/1), laser action starts at relatively low pressure (250 Torr), and the output energy then reaches a maximum near 400 Torr for 0.4% NF_3 and near 450 Torr for 0.2% NF_3. For lower Kr concentrations (He/Kr = 10/1), laser action starts near 350 Torr, and the output energy then reaches a maximum near 500 Torr for 0.4% NF_3 and near 600 Torr for 0.2% NF_3. The peak output energy is slightly higher than that obtained in the high-Kr concentration mixtures. With further decreases in Kr concentration (He/Kr = 20/1), laser action starts near 450 Torr, and the output energy continuously increases up to 700 Torr without reaching a maximum. In the present tests, the highest output energy (1.6 mJ) was obtained in a mixture of He:Kr: NF_3 = 100:5:0.2 at a total pressure of 700 Torr. The output energy density was 160 mJ/1, and the wall-plug efficiency was 0.06%.

It appears that the saturation or decrease of output energy at higher total pressure for He/Kr = 5/1 and 10/1 is due to excessive arc formation. As for the effects of NF_3, it appears that the higher concentration of NF_3 quenches the excited KrF^* molecule. It is the delicate balance between the rate of formation of KrF^* and the rate of quenching of KrF^* by NF_3 that determines the optimum ratio of Kr and NF_3.

The measured laser pulse shapes at various output energies are shown in Fig. 2. Each photograph is a multiple exposure of ten shots. At low energy, the output pulse shape appears to consist of two overlapping pulses of approximately equal amplitude. The pulse width (FWHM) is about 30 nsec (Figs. 2b and 2c). At higher output energy, the amplitude of the first pulse increased much more than the second pulse (Fig. 2a). The first pulse appears to be dominant. Its pulse width is about 10 nsec. In as much as the discharge duration is about 10 nsec, the first pulse must occur during discharge, whereas the second occurs in the afterglow. Similar behavior was noted in the XeF laser discussed below.

For the XeF laser, a discharge volume of $0.9 \times 0.33 \times 50$ cm = 15 cm^3 and line impedance of 0.04 ohm were used. The discharge voltage was 7 kV.



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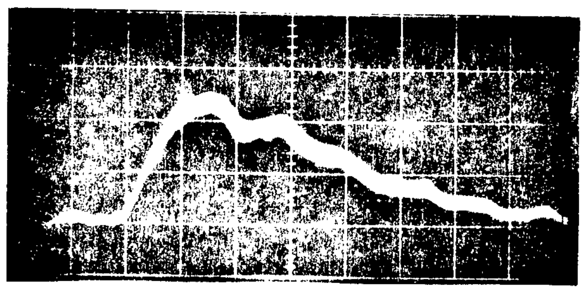

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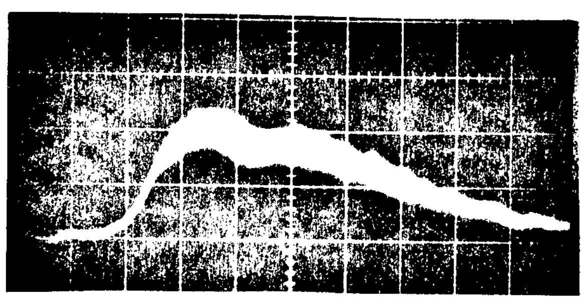

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Figure 2. Typical Output Pulse Shapes of KrF Laser at Various Energies. a. 1.6 mJ, 10 kW/div; b. 0.8 mJ, 10 kW/div; c. 0.2 mJ, 2.5 kW/div. Sweep speed, 10 nsec/div.

The laser cavity was a 10 m radius-of-curvature dielectrically coated total reflector with reflectivity greater than 97% and a flat dielectrically coated output mirror with 80% reflectivity. The separation between mirrors was 90 cm. The measured output wavelengths were 353, 351, and 349 nm.

Gas mixtures of He, 3-10% Xe, and 0.5-2.0% NF_3 were used at total pressures of 200-700 Torr. The measured output energy versus total pressure at various concentrations of Xe and NF_3 is plotted in Fig. 3. Each measurement was obtained by averaging over more than ten pulses. The output energy is shown to depend on the mole fraction of Xe and NF_3 as well as total gas pressure. This is contrary to the results of Burnham, Harris, and Djeu,[7] where the output energy depended only on the mole fraction of Xe and NF_3. The general pattern is similar to the case of the KrF laser. However, both the output energies and the NF_3 concentrations are an order of magnitude higher than in the KrF laser. The higher concentration of NF_3 used in the XeF laser indicates that concentrations of NF_3 up to 2% do not significantly change the discharge characteristics or cause excessive arcing. The use of low ratios of Xe/NF_3 indicates that the quenching of XeF^* by NF_3 is insignificant. This confirms the assumption used in Ref. 8.

The Xe concentration used here was much higher than that reported by Burnham, Harris, and Djeu[7] since the fast-discharge device used here, because of its short discharge time, low line impedance, and electrode geometry, can operate at relatively high Xe concentrations without excessive arcing.

The optimum gas composition was found to be $He:Xe:NF_3 = 100:4:2$. At the highest discharge voltage (9 kV), a maximum output of 10 mJ was obtained at 500 Torr. The peak output power was 1 MW. The maximum output energy density was 660 mJ/l, and the wall-plug efficiency was 0.5%. Compared with the results obtained previously,[8] output energy density of 70 mJ/l and wall-plug efficiency of 0.2%, the present results are an order of magnitude improvement in output energy density and a factor of 2.5 improvement in efficiency. Further improvement is possible with different gas additives, higher discharge voltages, and better impedance matching.

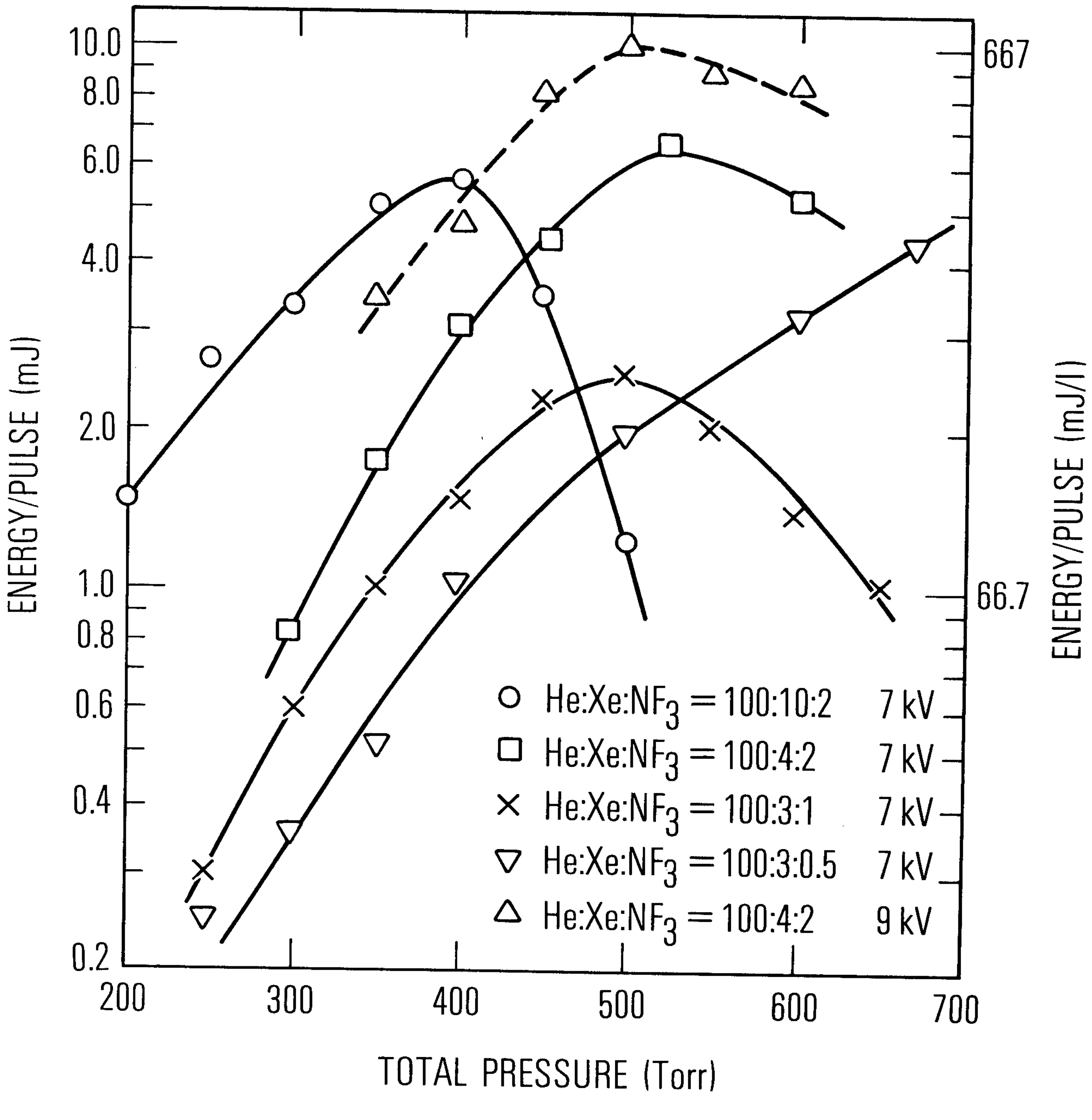
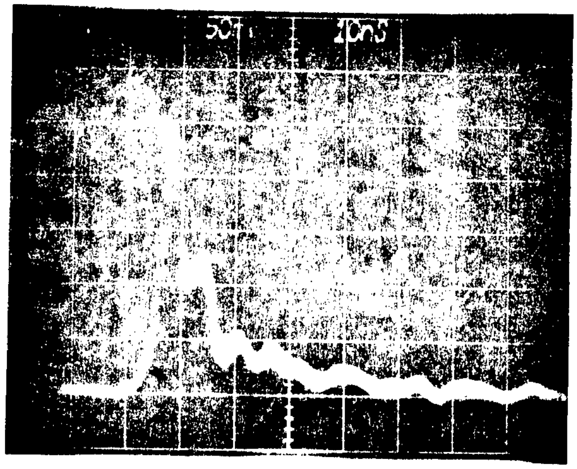


Figure 3. Measured Output Energy vs Total Pressure for Various Xe and NF_3 Concentrations

The Fresnel number of the cavity is relatively high, and the laser output beam contains higher-order modes. The typical output beam cross section is 0.6 × 0.4 cm near the output mirror, and the beam divergence is much less than 1 mrad. This is much better than in the N_2 laser, which is operated at superradiance mode.

Typical XeF laser pulse shapes at various output energies are shown in Fig. 4. Each photograph is a multiple exposure of ten pulses. At low energy, the pulse width (FWHM) is about 40 nsec (Fig. 4c). As the output energy is increased, a sharp peak develops and the pulse width decreases. The pulse width decreased to about 12 nsec at 2.5 mJ output (Fig. 4b) and about 6 nsec at 10 mJ output (Fig. 4a). The two-overlapping-pulses feature discussed earlier is also evident in Figs. 4a and 4b.



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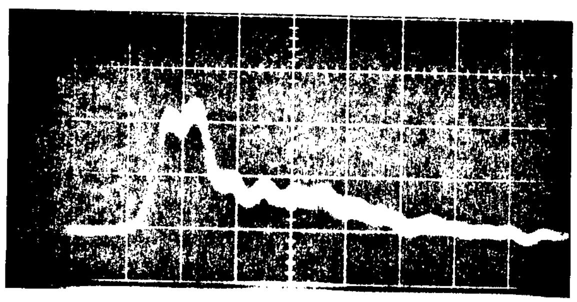

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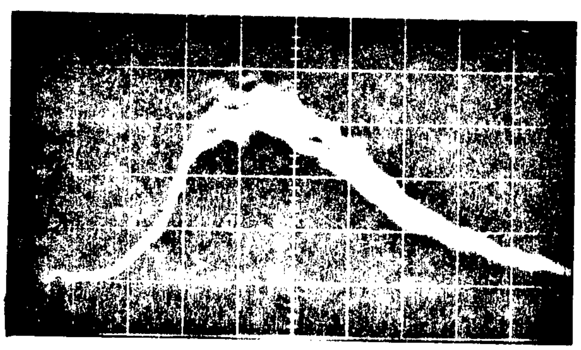

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Figure 4. Typical Output Pulse Shapes of XeF Laser at Various Energies. a. 10 mJ, 200 kW/div; b. 2.3 mJ, 50 kW/div; c. 0.3 mJ, 1.5 kW/div. Sweep speed, 10 nsec/div.

III. CONCLUSION

An order of magnitude improvement has been achieved in XeF/KrF laser output by optimizing gas composition, total pressure, and line impedance. Further improvement is possible as the excitation mechanism, gas kinetics, plasma stability, and fast discharges are better understood. The effect of various discharge voltages will be investigated in a later study.

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